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LEGIBILITY OF MILITARY SYMBOLS
ON A CATHODE RAY TUBE DISPLAY

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ABSTRACT

The legibility of selected military map symbols on a CRT display was determined by testing a symbol set of nineteen primary role descriptors symbols for military units using a tachistoscopic presentation technique. Simpler geometric symbols composed of fewer line components were more quickly recognized than complex ones, and were also the source of fewer errors. Symbols with circular or curved components were more likely to be confused with each other than with symbols composed of linear components.

INTRODUCTION

Automated data processing (ADP) is recognized as having great potential in the tactical command and control environment. Its use has been accelerated by the availability of more compact and powerful processors, new techniques of mass data storage, and new types of displays. Recognizing the increasing potential for automating the display of map-related information, the Military Symbology Working Group of the NATO Army Armaments Group Panel XIII has formulated a new set of standard symbology to accomodate ADP display techniques (7). DCIEM has undertaken to study the legibility of the proposed symbols on different types of electronic displays, and under a variety of conditions. This report describes the first stage in that investigation — a study of the legibility of the primary role descriptor symbols on a CRT display. These symbols comprise the most frequently used set of military map-marking symbols. Only those role descriptor symbols considered to be applicable to Canadian Forces units were studied --- a total of 19 symbols, shown in Fig. 1.
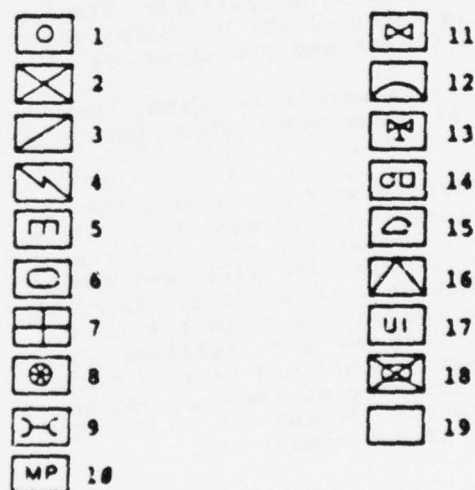

FIGURE 1
PRIMARY ROLE DESCRIPTOR SYMBOLS

Although much of the research on symbol legibility has been carried out using alphanumeric symbols, some work has been done on the relative discriminability of certain geometric symbols. Early work on geometric forms was motivated by Gestalt theory and was oriented toward finding the "best" or most easily recognized form. These studies were not con-

clusive, since recognition of a form depends not only on its shape, but on its similarity to other forms in the tested group, the number of such forms, and the observer's familiarity with them (Honigfeld, 1964).

Later experimenters, using larger sets of symbols, attempted to determine absolute rankings of symbol shapes on the basis of discriminability. Again, there was a lack of agreement, although a review by Vanderkolk et al. (1975) states that the triangle, square, circle, X, and rectangle (the simple geometric forms) are generally ranked highest in legibility. These authors suggest that one possible explanation for the diversity of findings concerns the confounding of symbol size and symbol area.

Davis (1969) concluded that several factors have limited the applicability of the studies on symbolic coding:

1. Some studies included a biased representation of form families (e.g., many circular or elliptical forms, and few linear ones);

2. Few experiments were run using a realistic display situation, either in terms of the hardware, or in terms of exact symbol design and presentation;

3. In some cases, conclusions were drawn from limited sets of symbols; total codes were not tested.

Narsetta and Shurtleff (1966) have investigated the legibility of military map symbols to determine the minimum acceptable resolution for symbol legibility on a television monitor. Thirty military unit symbols with different combinations of role and size designation were studied. Four of these roles were the same as the ones used in the current study. More recently, a large study on the relative discriminability of 218 tactical air symbols was carried out by Williams and Teichner (1979). Accuracy of response and response latency were used to provide information on the discriminability and confusability of the symbol set.

These evaluations of symbol codes have produced only very general guidelines for the design of legible symbols. The lack of specific recommendations on symbol design requires that any particular symbol set under consideration be experimentally tested for legibility.

METHOD

Subjects

Eight subjects volunteered to participate in the current experiment. They were all employees of DCIEM who had no experience with military maps or symbology. All had normal or corrected vision of at least 20/20, as tested using a wall chart.

Apparatus

No specific design standards are available regarding the exact shape or size of the symbology for the primary role descriptor. Although the nature of some symbols precludes much variation in design (e.g., symbols with lines drawn between certain points within the rectangle: symbols 2,3,7 in Fig. 1) others can be drawn in a variety of ways, by changing the size and position of symbol components within the rectangle. The design details of the symbols used in this experiment are given in Fig. 2.

Symbols were presented on a monochrome vector graphics display (Digital Equipment Corp. Model VR17) with a resolution of 1024 x 1024 points in a display area of 24.5 x 23.8 cm. Stroke drawing techniques were used to generate the symbols on the display. Symbols were .56 cm high (25.3' arc subtense at the 76 cm viewing distance) and .89 cm wide (40' arc subtense). Appendix A describes the rationale used in determining symbol subtense.

Since a CRT is a light-emitting display, symbol luminance depends on the number of points or lines used to draw the symbol. Thus symbols with only a few lines drawn inside the unit rectangle (e.g., Fig 1, symbols 1,3,12) will have lower luminance than symbols with many lines (e.g., symbols 14,18), assuming that they are all drawn at the same intensity setting. Since this luminance difference could be used as a means of differentiating between symbols, symbol luminances were equated under software control to decrease the intensity of symbols with more lines and to increase the intensity of those with fewer lines. Only the role descriptor portion of the symbol was adjusted. The unit rectangle was left at median intensity. Average symbol luminance was 2.75 ft-L with a range of .7 ft-L (see Appendix A for a description of the luminance measurement technique and data on individual symbol luminances). Symbol contrast ratio was 26:1 measured as described in Appendix A.
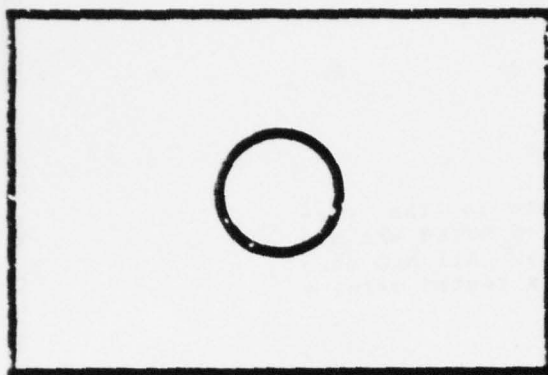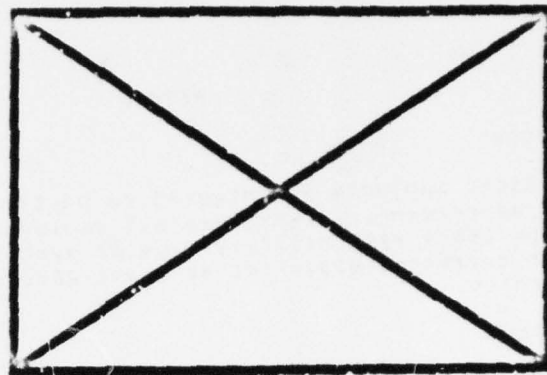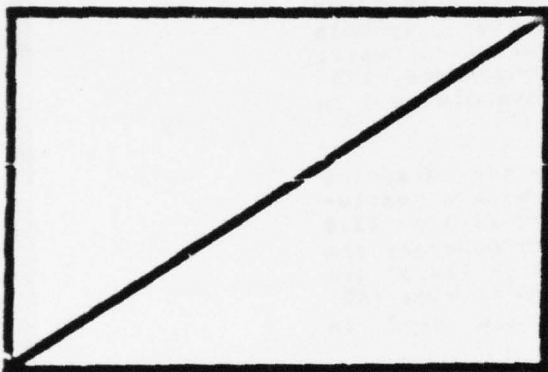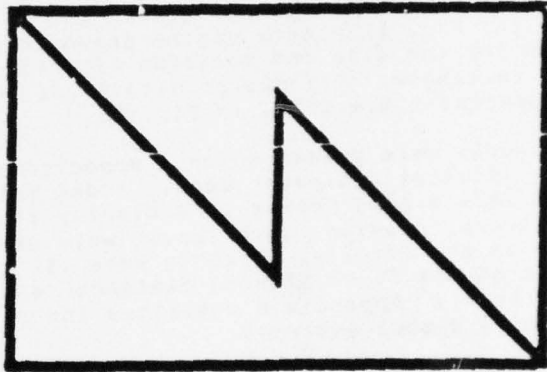
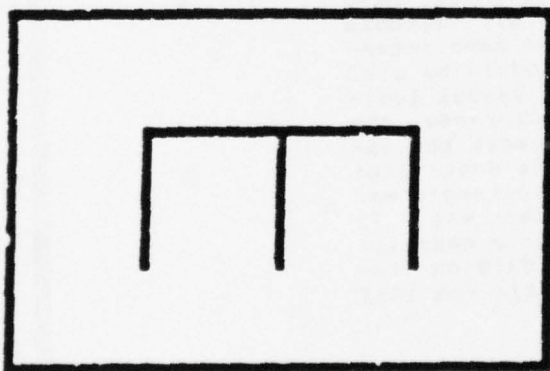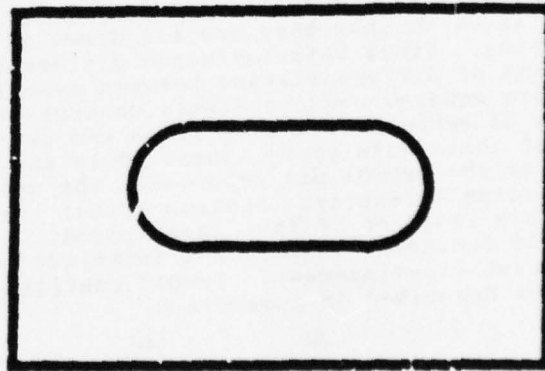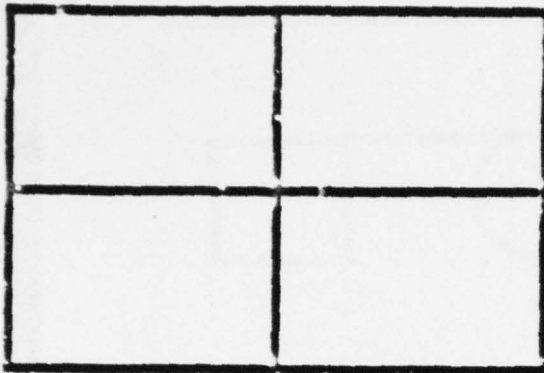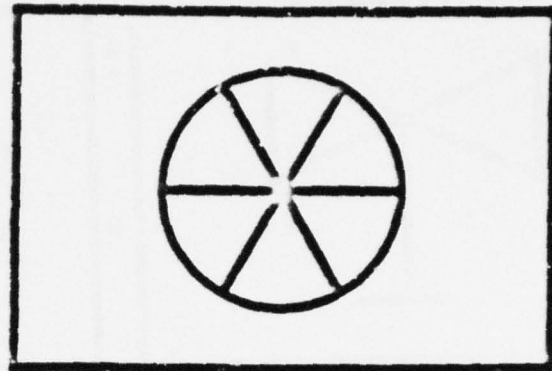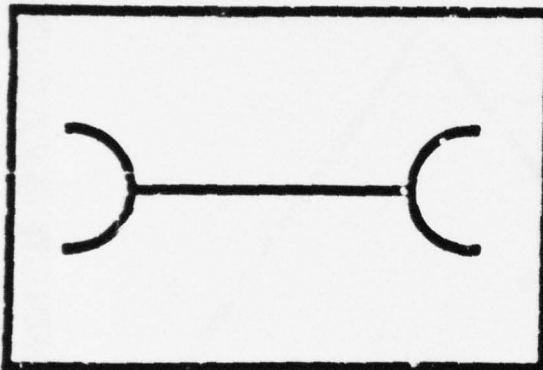FIGURE 2a
DETAILED DESIGN OF PRIMARY ROLE
DESCRIPTOR SYMBOLS

7

8

9

10
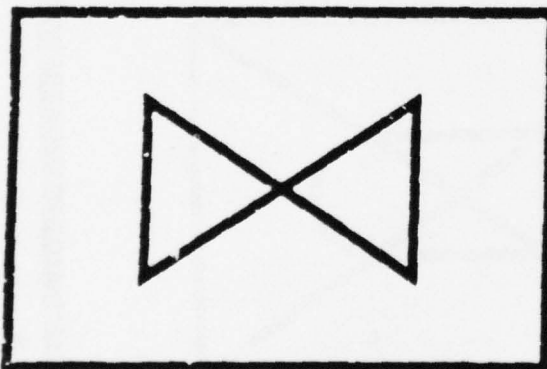
11

12

FIGURE 2b

DETAILED DESIGN OF PRIMARY ROLE
DESCRIPTOR SYMBOLS

13

14

15
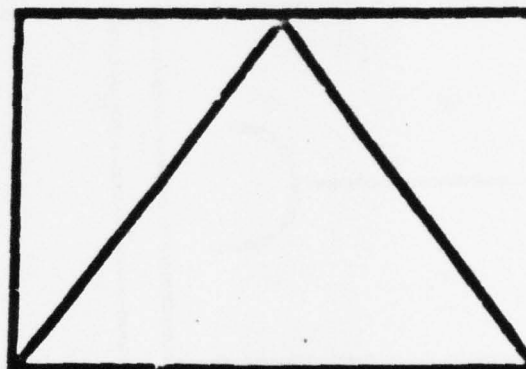
16
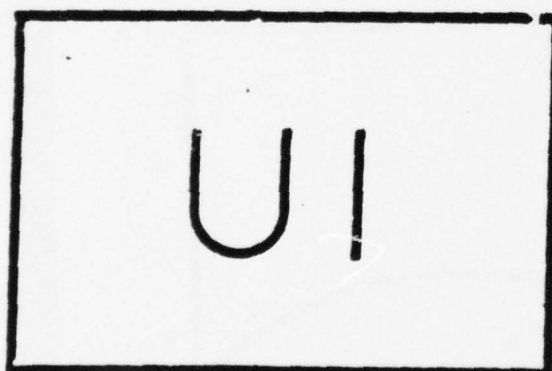
17
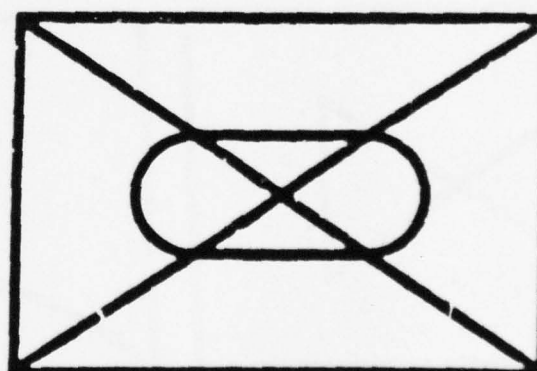
18

FIGURE 2c
DETAILED DESIGN OF PRIMARY ROLE
DESCRIPTOR SYMBOLS
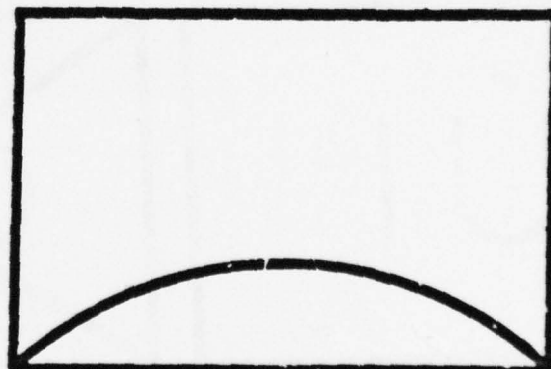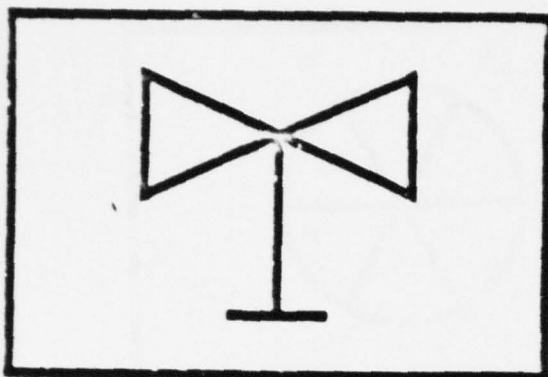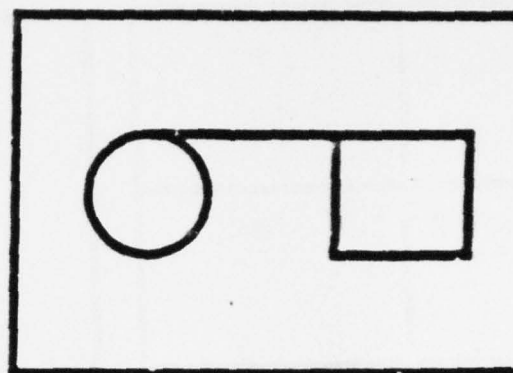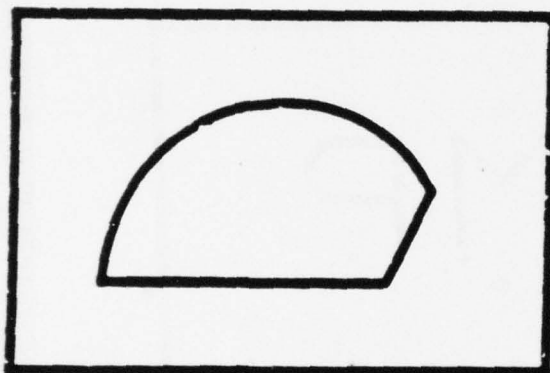
Subjects were seated in front of the display screen in a small booth constructed of moveable partitions, which provided both acoustic shielding from equipment noise (sound pressure level=63 dbA inside the booth) and a uniform visual background to minimize reflection from the display screen. Since the maximum expected distance between an observer and the display screen in the operational situation is 76 cm (30"), this viewing distance was used in the experiment. Head fixation was maintained by use of a chin rest. Response selection was effected by indirect cursor positioning from a Summagraphics digital tablet placed in front of the display.

Experimental Design

The experiment was a factorial design: 19 (symbols) x 2 (sessions) x 8 (subjects) with 10 observations per cell, i.e., 190 observations per session, with the symbols randomly distributed over the 190 observations.

Procedure

The legibility test used in this experiment was a tachistoscopic recognition task in which a symbol was randomly selected and presented briefly at a fixed location on the CRT display. Each subject had an initial practice session of 60 trials for familiarization with the equipment, symbol set, and procedure. A short refamiliarization period (consisting of 20 trials) started each experimental session. Experimental sessions were about an hour in length, with a five minute break in the middle to alleviate boredom and fatigue.

Each trial began with the presentation of a rectangular fixation symbol for 4 seconds. There was a 0.5 sec. blank interval to announce the test symbol which was presented for 0.032 sec. A solid rectangular mask then appeared for 2 sec. at the location of the test symbol, followed by a randomly-ordered matrix of the 19 symbols for 10 sec. The matrix was positioned on the screen below the test symbol location and was arranged in four rows of 4 symbols and one row of three. The cursor symbol (a box with an 'X' in it) was displayed simultaneously with the matrix. The subject moved the cursor symbol over the desired matrix symbol using the cursor controller and then pushed a button on the cursor controller to indicate his choice to the computer. The chosen symbol flashed for 2 sec. after which the matrix was removed from the screen.

The subject initiated the next trial by selection of the word 'NEXT' that was displayed to the right of the screen (or to the left for left-handed subjects) after the removal of the matrix. This technique also fixed the start-

ing position of the subject's symbol acquisition movement.

Data collected during each experimental trial consisted of the symbol presented, the symbol chosen and the time (accurate to 1/60 sec.) between the start of presentation of the matrix and the subject's response.

RESULTS

Time Data

A four-way analysis of variance was carried out on the data on response times, treating subjects as a random factor and the remaining factors as fixed. In the entire experiment, there were ten trials in which the subject did not make a response, probably because of involuntary eye movement at the time of the symbol presentation. These instances represented only 0.3% of the data points and were distributed over subjects, symbols and sessions. The value used for each missing data point was the value of the cell mean, and the error degrees of freedom were reduced accordingly.

Response time in this experiment can be considered to consist of a variable decision time plus a fixed delay due to motor response. This is reflected in the positive skew of the response time data. In order to reduce the correlation between the mean and standard deviation, and so better satisfy the assumptions of the analysis of variance model, a transformation, $\log(x-0.8)$, was applied to the data (Winer, 1962).

The analysis of variance is shown in Table 1. All two-way interactions and main effects not involving replications, except for the symbol x session interaction, were significant at the 0.01 level. All other interactions were not significant at this level. The subject x session interaction is plotted in Fig. 3. For all subjects but one, average response time dropped in the second session, by about 7%.

The existence of a symbol x subject interaction indicates that the pattern of subjects' response times was not the same across symbols. However, it should be noted that the main effect F ratios are considerably larger than the interaction ratios, thus suggesting that this interaction contributes little to the variance in response times to symbols.

FIGURE 3

MEAN RESPONSE TIME FOR EACH
SUBJECT IN EACH SESSION
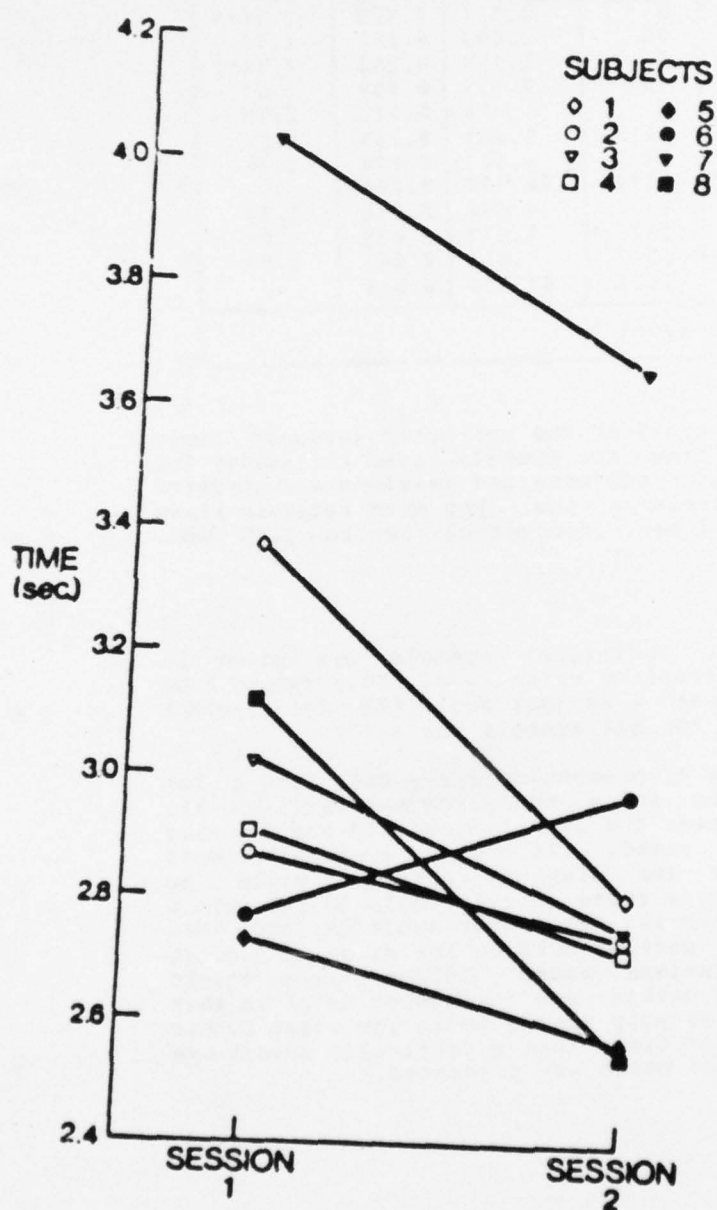
TABLE 1
ANALYSIS OF VARIANCE OF TIME DATA

SOURCE OF VARIATION	DF	SS	MS	F
Sy (Symbol)	18	30.109	1.672	30.18**
Su (Subject)	7	16.534	2.362	40.68**
Sy x Su	126	15.767	0.125	2.16**
Se (Session)	1	2.923	2.923	52.76**
Sy x Se	18	1.883	0.104	1.80
Su x Se	7	1.769	0.252	4.36**
Sy x Su x Se	126	7.529	0.059	1.03
R (Replication)	9	1.098	0.122	2.20
Sy x R	162	9.031	0.055	1.01
Su x R	63	4.685	0.074	1.28
Sy x Su x R	1134	64.388	0.056	.98
Se x R	9	0.666	0.074	1.33
Sy x Se x R	162	8.977	0.055	.95
Su x Se x R	63	4.013	0.063	1.09
Sy x Su x Se x R	1124	65.251	0.058	

** Significant at 0.01 level

Figure 4 shows a graph of the corrected response times (mean untransformed time for symbols named correctly) for each symbol averaged over subjects and sessions and ordered on the basis of increasing time. The mean response times range from just under 2 sec. for symbol 19 to 3.75 sec. for symbol 11.

Errors

Percent errors for individual symbols are given in Table 2 in order of increasing error rate. They ranged from under 1% for symbols 3 and 6 to just under 10% for symbols 10 and 18. Mean error for all symbols was 4.47%.

An appropriate way of presenting error data from a legibility experiment is in a confusion matrix (Table 3). Here the columns represent the symbol presented and the rows represent the symbol named. If all the symbols had been correctly named, only the diagonal entries would be non-zero, and in this case those entries would be 160, since each symbol was presented 160 times over subjects and sessions. The non-zero entries outside the diagonal provide information on the confusions made. Column error totals (the bottom line in the matrix) are the number of times that a presented symbol was wrongly named, while row error totals give the total number of times that a particular symbol was called instead of another which was presented.

FIGURE 4

MEAN RESPONSE TIMES FOR SYMBOLS
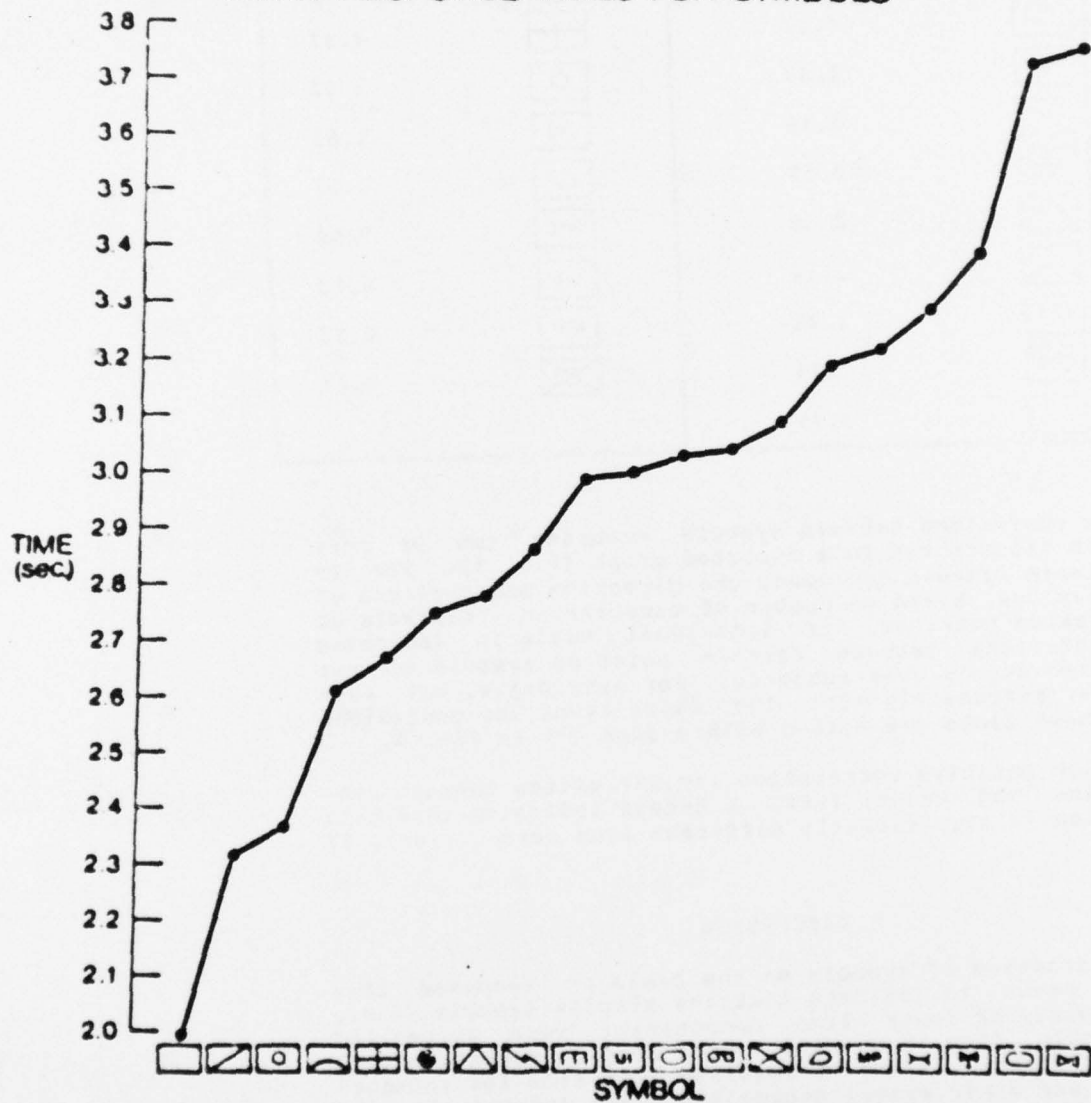
TABLE 2
ERROR RATES FOR SYMBOLS

SYMBOL	% ERROR	SYMBOL	% ERROR
	8.62		4.37
	8.62		4.37
	1.88		5.62
	2.50		5.62
	2.50		5.62
	2.50		7.50
	3.12		8.12
	3.75		9.37
	3.75		9.37
	3.75		

The confusions between symbols occuring two or more times are illustrated in a directed graph (Fig. 5). The arrows between symbols represent the direction and strength of the confusions, based on number of occurrences. Analysis of the confusion matrices for individual subjects indicates that confusions between certain pairs of symbols are not distributed evenly over subjects. For many pairs, one subject was responsible for the majority of the confusions made. These links are marked with a star (*) in Fig. 5.

A high positive correlation (r=.96) exists between response time and error rate. A t-test indicates that this correlation is significantly different from zero (t=14.1, 17 d.f.).

DISCUSSION

The ordering of symbols on the basis of response time (Fig. 4) seems to indicate that the simpler symbols (i.e., those composed of fewer line components) were recognized more quickly than those with a more complex geometric pattern. For example, symbol 3 required less time for recognition than any other symbol except the blank (symbol 19).

TABLE 3
MATRIX OF SYMBOL CONFUSIONS SHOWING THE
NUMBER OF TIMES A GIVEN SYMBOL WAS NAMED FOR ANOTHER

| SYMBOL NAMED		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	TOTAL ERRORS
○	1	151	0	0	0	0	0	0	0	3	0	0	1	0	0	1	3	0	4	0	9
⊠	2	0	156	0	0	0	0	0	4	0	1	0	2	0	0	0	0	0	0	1	8
◺	3	0	0	155	0	0	3	0	0	0	0	0	0	1	0	0	0	1	0	6	2
◿	4	0	0	0	157	1	0	0	0	0	0	0	2	0	0	0	9	0	0	0	3
◫	5	0	0	0	0	154	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
◎	6	1	0	0	0	0	159	1	1	2	6	0	0	0	0	0	3	0	0	5	2	21
⊞	7	0	0	0	0	0	0	0	153	0	0	0	0	0	0	0	0	1	0	1	2
⊕	8	7	0	0	0	0	0	0	0	156	0	0	0	0	0	0	2	0	0	0	9
⋈	9	0	0	0	0	0	0	0	0	0	148	0	0	0	1	0	0	0	0	0	1
MP	10	0	0	0	0	6	0	0	0	0	0	145	0	0	0	2	0	0	7	1	0	10
⋈	11	0	1	0	0	0	0	0	0	0	5	0	151	1	2	0	0	0	0	6	0	15
◠	12	0	0	0	0	0	0	0	0	0	2	0	0	155	0	0	2	0	0	0	1	5
⊤	13	0	0	0	0	0	0	0	0	0	0	1	0	153	0	0	0	0	0	0	1
⊗	14	0	0	0	0	3	0	0	0	0	0	3	0	0	1	154	0	0	0	0	0	7
◍	15	0	0	0	0	0	0	0	0	0	0	2	0	1	9	0	151	0	0	2	5
◻	16	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	156	0	0	0	1
∪	17	1	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	147	0	0	4
◰	18	0	2	0	0	1	0	1	0	1	0	1	0	0	0	0	0	0	1	145	0	7
▭	19	0	0	0	1	1	0	1	1	0	0	2	1	2	1	3	1	1	0	1	154	16
TOTAL ERRORS		9	3	1	2	5	1	7	4	11	15	0	5	6	6	0	2	13	14	6		
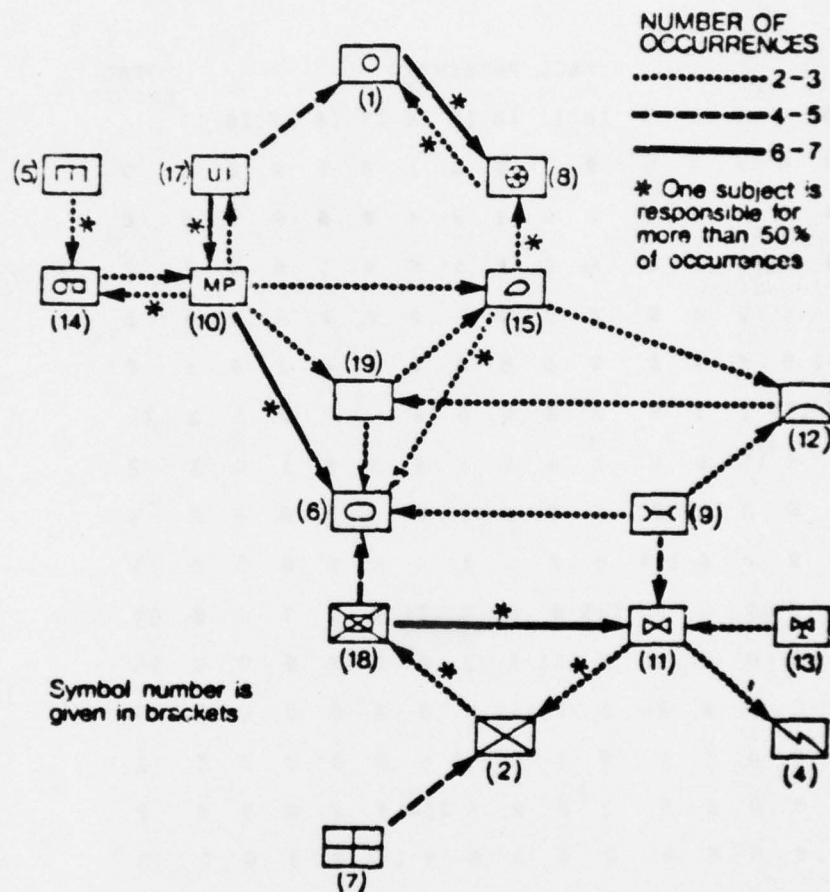
FIGURE 5
DIRECTED GRAPH OF SYMBOL CONFUSIONS

Symbol 18, a complex symbol, required more time than did either of its subcomponents alone (symbols 2 and 6). Current theories of pattern recognition based on feature extraction (Lindsay and Norman, 1977) predict this result; as the number of individual features of a symbol increases, more time is required for their extraction and processing.

The high positive correlation between response time and errors indicates that subjects were not sacrificing accuracy in order to be able to recognize symbols more rapidly. Symbols which took longer o recognize --- the more complex ones --- were also the source of more errors. Other researchers have found the same correlation (Williams and Teichner, 1979). It is a well-established principle that simpler forms are easier for the human to process (Zusne, 1970). It is preferable, therefore, that symbols for coding be kept simple in form.

Although it is difficu . to state   acceptable limit for error in these kinds of experiments, Honigfeld (1964) claims that a criterion of 5% accuracy in responding to a code under lab conditions has been agreed as adequate. The overall error rate in this experiment satisfies this criterion. The confusion matrix gives an indication of the nature of the errors. It is notable that confusions were not necessarily symmetric: for example, symbol 11 was named for symbol 18 in 6 instances, but the reverse error occurred only once. A particularly striking example of non-symmetric confusion in this experiment involved symbol 6 (the elliptical symbol); although it was misnamed only once (error rate 0.62%), it was named instead of other symbols a total of 21 times. A tendency for imperfectly-perceived forms to appear round is a well-documented phenomenon (Zusne, 1970).

A distinction can be made between symbols which are repeatedly the source of errors (i.e., are misnamed), such as symbols 1,9,10,17, and 18 and those which are the recipient of such errors, like 6,10,11, and 19. It is possible that redesign of symbols in the latter set would reduce the overall error, although these symbols are not themselves the ones misread.

The fact that confusions between particular pairs of symbols are often confined to one or two subjects makes it impossible to generalize these findings to a wider subject population. However, from Fig. 5 it can be seen that the confusions fall into two main groups: those involving circular or curved symbols (e.g., symbols 1,6,8,15) and those involving angular or more linear symbols (e.g., symbols 2,9,11). Another separate subgroup of confusions perhaps could be defined by the alphabetic-like symbols (5,10,17). Confusions tend to occur within groups, and do not cut across group boundaries, except through symbols 9 and 18,

which have both curved and linear components. This finding is consistent with Davis' (1969) conclusion that for maximum coding efficiency, symbols should differ strongly in shape. Zusne (1970) has provided a preliminary classification of important form parameters, based on factors such as area, center of gravity, number of sides, angularity and symmetry. Further experimentation will be necessary, however, to determine the exact parameters that should be varied to maximize the differences in shape of the role descriptor symbols in this symbol set.

In this experiment, recognition is based on the role descriptor portion of the symbol, which is sometimes considerably smaller than the overall target. In the case of symbols 1, 18, and 17 the role descriptor subtends only 9' arc, which may be too little for reliable identification (Gould, 1968). It is possible that increasing the size of the role descriptor portion of these symbols might aid their recognition. However, it is also possible that the size of the role descriptor (as well as its shape) is being used as a redundant cue to assist discrimination between symbols of similar form, and that elimination of this cue would have a negative effect. Davis has suggested that redundant size coding may be advantageous for coding radar symbols.

Application of these results to symbols in an operational environment would have to take into account the factors of semantic content, or meaning, of the symbols, and the tactical context presented in conjunction with the symbols on a map display.

CONCLUSIONS

In agreement with previous studies on the legibility of geometric forms, the experiment has shown that the simpler role descriptor symbols are more quickly identified, with fewer errors, than are more complex symbols. Patterns of confusions between symbols are related to the nature of the primary role descriptor form (linear vs. curved). Further study can determine the parameters of symbol form which are important for symbol recognition, and can indicate possible redesign that might avoid some confusions that presently occur.

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APPENDIX A

STIMULI

Symbol Size

Symbol size is of primary importance in designing legible symbols. From a practical point of view, it is preferable that the unit symbols be no larger than necessary, since this will maximize the number of symbols that can be displayed simultaneously without overlap.

Recommendations for symbol height, in terms of visual angle subtended at the viewer's eye, vary widely, depending on the type of symbol studied, the display system used, the environmental conditions and the criterion of performance. A symbol subtense of 12' arc is the typically accepted minimal visual angle for alphanumeric data presented on television and other electronic displays (Van Cott and Kincade, 1970). However, a major review of legibility research by Vanderkolk et al. (1975) concludes that a symbol subtense of 22-26' arc is required under normal operating conditions. Under ideal conditions a subtense of 16' is tolerable, but not recommended. Sub-optimal operating environments (e.g., extremes of illumination, vibration) necessitate larger symbols.

In operational use, there is a requirement for up to three lines of optional alphanumeric text to be positioned beside the unit symbol. If the alphanumeric symbols subtend 12' arc, and there is 1' arc between each line the total space required is 38' arc. A trade-off can be made, therefore, between the requirement to have symbols as small as legibly possible, and the requirement to have enough space adjacent to the symbol for associated text. Since the text can be allowed to extend to some degree above the top and below the bottom of the unit symbol, a symbol subtense of 25' arc was used in this experiment.

Symbol Luminance and Contrast

Besides being regulated by the intensity level set in the display software, luminance on the CRT used in this experiment was controlled by having a constant software display list length to fix the refresh rate of the display, and by having the viewer-activated brightness control at a fixed position.

Luminance was measured in two ways:

1. by measuring the luminance of the spots or lines used to construct the symbols,

2. by measuring overall luminance of the entire sym-
    bol.

From these measurements, plus a measure of the background
luminance, contrast ratio (C) was calculated as:

$$C = \frac{Bs - Bo}{Bo}$$

where Bo = background luminance
Bs = spot or symbol luminance

Recommendations in the literature for these parameters
are typically 25 ft-L (Gould, 1968) for symbol luminance and
between 4:1 and 30:1 for contrast (Howell and Kraft, 1959).

A Gamma Scientific photometer with a microscope attach-
ment was used to measure spot luminance. A single spot of
software intensity level 3 (the same as the unit rectangle)
was positioned below the location of the prompt symbol on
the display screen. The photometer probe was placed at the
center of the spot, where the maximum luminance would occur
(assuming that luminance is distributed in a Gaussian manner
across the spot). Because the spot tended to drift continu-
ously, six readings were averaged, giving a spot luminance
of 469 ft-L. A similar reading taken on the blank screen
gave a background luminance of 8 ft-L, for a spot contrast
ratio of 50:1.

Symbol luminance was measured within a reticle ring po-
sitioned around the unit symbol so that the circle just
touched the corners of the unit rectangle. The luminance of
each symbol measured in this way is given in Table A-1.
Average symbol luminance was 2.75 ft-L. The range of lumi-
nances was .4 ft-L or 15% of the average. Background lumi-
nance of the screen, measured over the same area under the
ambient light conditions used in the experiment, was .1
ft-L. This gave a mean symbol contrast ratio of 26:1.

TABLE A-1
SYMBOL LUMINANCES

SYMBOL	LUMINANCE (ft-L)	SYMBOL	LUMINANCE (ft-L)
1	2.6	11	2.6
2	2.7	12	2.7
3	2.6	13	2.7
4	2.8	14	2.7
5	2.9	15	2.9
6	2.8	16	2.6
7	2.7	17	2.8
8	2.8	18	3.0
9	2.8	19	2.7
10	2.9		

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